EFFECT OF COAL RANK ON COMPOSITION OF LOW-TEMPERATURE TAR FROM A BENCH-SCALE FIXED-BED CARBONIZER

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The Morgantown Coal Research Center of the U.S. Bureau of Mines has conducted an extensive research program on the effect of changing carbonization conditions on the detailed composition of low-temperature coal tars. Previous publications on the influence of carbonization temperature, carrier gas, and carbonization method have been presented for 10 different low-temperature tars produced from a Colorado subbituminous coal (1, 2), and for 5 different low-temperature tars produced from a Pittsburgh-seam high-volatile A bituminous coal (3).

This report concerns the tars produced in an inert atmosphere at 500° C in fixed beds from seven different coals representing major ranks of humic coals and cannel coals. Analyses were made for the amounts of about 100 compounds, and for several classes of compounds, in each tar and its corresponding light oil, in terms of the coal as it would be charged in a commercial process.

The purpose of this study was to obtain enough detailed information on the amounts of compounds of commercial interest to make an economic evaluation and comparison of the product tars and light oils from coals of various rank carbonized under the same conditions. These relative effects of coal rank are also usable in regard to previous results with commercially feasible processes such as fluidized-bed or entrained-bed methods.

Very little research has been done on the variation of the detailed composition of tars due to coal rank. Recently Maher carbonized two different Australian coals (82 and 89 percent carbon) in a static-bed retort at 500° C (4). Numerical quantitative results were presented for the products from only one of these coals under these conditions, however. Even so, he could draw a few conclusions, mainly that the proportion of aromatic constituents was greater with the higher rank of coal.

EXPERIMENTAL

The seven different coals used in this work are described in Table 1. Samples sieved from 8 to 42 mesh were used to charge the carbonizer.

The carbonizer and product collecting system are shown in Figure 1. The carbonizer consisted of a vertical 43-in. hinged tubular furnace (4,540 watts, 230 volts) holding a 62-in. by 2-in. OD Vycor tubing reactor. The tubing in turn held a 36-in. long thimble, constructed from fine mesh stainless-steel screen and designed to give an approximately 1/4-in. annular space with the Vycor tubing.

Caking coals swelled sufficiently to block the passage of gas through the annular space, so for these coals the inside of the thimble was lined with pure silica sea sand that had been washed and ignited, and filled with a core of coal. This sand lining was made by inserting a 1-in. ID glass tubing to the bottom of the thimble, placing a 1/4-in. Vycor thermocouple well inside the glass tubing, and adding sand, of particle size retained by a 42-mesh screen, to the space between the thimble and the glass tubing to a depth of about 6 in. Coal was then added through the glass tubing while the tubing was gradually pulled up so that the coal level was always about 1 in. above the bottom of the tubing. When the coal and sand levels were about equal the tubing was tapped gently with a rubber mallet to settle the particles, and the addition of sand and coal then repeated until the thimble was essentially full.

The inside thermocouple well held four chromel-alumel thermocouples (TC 5 through TC 8) for determining the temperature of the coal. The outside thermocouple well, which was inserted between the thimble and the reactor tubing, held four thermocouples (TC 1 through TC 4), for determining the powerstat settings for the four independent heating elements, which consisted of 6-in. sections at the top and bottom of the furnace, and two 14-3/4-in. sections in the central portion. A sectioned furnace was required in order to maintain the same temperature throughout the length of the coal bed.

A tar-receiver, consisting of a pot with side arm, was attached to the bottom of the Vycor reactor tubing via a large standard taper joint containing a Teflon sleeve. The No. 1 trap was cooled with ice, No. 2 with powdered Dry Ice, and No. 3 with Dry Ice and trichlorethane, all connecting tapered joints having Teflon sleeves. A column filled with 3- to 8-mesh silica gel was used to recover traces of nongaseous product escaping the traps, followed by a manometer to show that the system was under slight positive pressure, and a gas washing bottle to indicate gas flow.

Coal charges were about 270 g for the cannel coals, 300 g for the bituminous coals, and 560 g for the subbituminous and lignite coals. No sand was used with the latter two in order to obtain enough tar for the assay. The entire system was purged thoroughly with nitrogen, via the nitrogen inlet tube, before each run, and a small, steady stream of nitrogen was used throughout the run. The gas washing bottle was used to confirm the flow of gas. Each run was made at a maximum of 500° C, about 40 minutes being required to reach this temperature. Usually the run was continued at 500° C for about 20 minutes, and then the furnace was turned off because the evolution of yellow aerosol had ceased. Most of the tar was received in the pot, while progressively smaller amounts of tar, light oil, and water were in the three traps.

The contents of the pot and traps were combined, and the water was removed and measured by azeotropic distillation in a Stark and Dean apparatus, using the light oil in the product for the carrier. The light oil was then separated from the tar as a single fraction boiling up to 160° C, and extracted with 10-percent aqueous potassium hydroxide solution to remove any trace of phenols and water that may have been taken over as an azeotrope. The analyses for the individual compounds and classes of compounds in the tars and light oils were made according to a Bureau of Mines procedure (1) based primarily on liquid and gas chromatography. An abridged outline of this procedure has been given (2) and additional information presented (3).

RESULTS AND DISCUSSION

The yields of individual light oil constituents in pounds per ton of dry coal are shown for the seven different coals in Table II. The yields of the major light oil compound classes are shown in Figure 2, in which the unidentified individual constituents consist almost entirely of nonaromatics such as branched-chain and cyclic aliphatics. Because of the low boiling range of this light oil, only a few benzene aromatics are theoretically possible, and these are all readily identifiable.

As shown in Table II, some of the major aromatic constituents, such as benzene, toluene, and m-xylene, appear to have a general, if not completely consistent, decline in yield with decrease in rank of the normal coals, although the trend for total aromatics is not as clear. The predominant xylene isomer from all seven coals is m-xylene, in the direction of thermodynamic equilibrium. The most striking features of Figure 2 are the high yields of light oil from both cannel coals, due primarily to straight-chain aliphatics, and the large difference in yields of light oil from Pittsburgh coal from two different locations in the seam. The lower yield of 11.40 pounds per ton of coal from Marion County compared to Arkwright coal is in agreement with the 11.20 pounds previously obtained from this same coal in an externally heated 4-in. diameter entrained-bed carbonizer at 538° C (3), and hence cannot necessarily be ascribed to losses.

Table III and Figure 3 show the yields in pounds per ton of dry coal of the fundamental fractions of the total tar, obtained by solvent extractions. The most prominent feature is the extra high yields of tar from the cannel coals, due to the neutral oils. There was a significant difference in the yields of tar from Pittsburgh coal from the two different locations in the seam, the Arkwright coal again giving the higher yield.

Tables IV and V and Figure 4 show the total tar acids and total purified tar bases in pounds per ton of dry coal. The two points emphasized by Figure 4 are the much lower yields of tar bases compared with tar acids for all coals, and the clearly defined decline in yield of total tar acids with decrease in rank of the normal coals. Figure 5, which shows the low-boiling phenols by classes, does not indicate any particular trend with rank; the total cresols, for example, did not vary greatly for the five normal coals. Also, Table V shows that the five lowest boiling phenols totaled about 5 or 6 pounds per ton of each of these five normal coals. Table V also shows that the most prevalent of the six xylenol isomers from all seven coals is 2,4-xylenol, in the direction of thermodynamic equilibrium (5).

Table IV shows that highly alkylated quinolines, such as 2,4-dimethylquinoline which is the most prevalent isomer, make up the bulk of the distillable tar bases. The amounts of pyridines were too small to see by gas-liquid chromatography of the total purified tar bases. In a previous detailed analysis of the tar bases from a 500° C fluidized-bed carbonization of Arkwright mine coal (5), just eight individual alkylated quinolines, especially those alkylated in the 2- and 4- positions, made up fully one-fourth of the total distillable tar bases.

Table VI and Figure 6 show the yields, in pounds per ton of dry coal, of the major classes of compounds making up the high-quality neutral oil, which is an essentially colorless oil containing all the aliphatics (paraffins and olefins) and dinuclear aromatics (naphthalenes and biphenyls) from the entire tar, there having been no separations by distillation in the recovery of this material. The "other paraffins" and "other olefins" in Table VI consist of the 2-methylalkanes, branched α-olefins, and trans-internal olefins determined by quantitative infrared analysis. The "not identified" aromatics in Figure 6 include the C_{12} and C_{13} biphenyls, which were identified as such, higher alkylated biphenyls, and a variety of compounds containing five-membered rings, such as dibenzofurans. In a previous detailed analysis of the neutral oils from the 500° C fluidized-bed carbonization of Arkwright mine coal (6), a total of nine different classes of polycyclic compounds containing five-membered rings was found.

The most obvious feature shown in Figure 6 is the extra large yield of high-quality neutral oils for both cannel coals, due to every class of compounds except naphthalenes. Table VI shows a definite increase in yield of total olefins with decrease in rank of the normal coals, excluding the subbituminous coal. However, when this same subbituminous coal was carbonized at 500° C in an externally heated entrained-bed, the yield of total olefins was 15.9 pounds per ton of dry coal (2), which is consistent with the trend mentioned above. Total naphthalenes fell in the range of about 4 to 11 pounds per ton of dry coal for the seven different coals. This is compared with the approximately 6 pounds of naphthalene itself obtained from the average coke oven tar.

Naphthalene itself is quite low in all the low-temperature tars, as shown in Figure 7, varying from about 0.04 to 0.85 pound per ton of dry coal. The classes of alkylnaphthalenes, determined by ultraviolet spectroscopy, ran as high as pentamethyl for all seven coals. Figure 7 shows that there was a definite decline in yield of total naphthalenes with decrease in rank of the normal coals. Table VII shows that for six of the seven tars there was substantially more 2-methyl than 1-methylnaphthalene, in the direction of thermodynamic equilibrium at 500° C. The ratio of 2-methyl to 1-methyl for the Arkwright mine coal was 58 to 42, in excellent agreement with the ratio of 57 to 43 for this same coal carbonized at 500° C in a fluidized bed (6).

Figure 8 shows, again, that the yields of aliphatic hydrocarbons from both cannel coals are exceptionally high compared with the normal or humic coals. The yields of "other olefins" alone, which constitute the β- and branched olefins, are greater for each cannel coal than the total aliphatics for each of the normal coals. The "other paraffins" are largely 2-methylalkanes, with lesser amounts of other branched paraffins. The breakdown of the straight-chain paraffins and olefins into individual compounds is shown in Table VIII. Considering the two individual compounds making the highest contributions to the total straight-chain fraction from each tar, these increase from about C_{17} to C_{24} n-paraffins with decreasing rank for the first four normal coals. However, the two highest compounds in the lignite tar are olefins, namely 1-heneicosene (C_{21}) and 1-docosene (C_{22}). No aliphatic hydrocarbons higher than C_{36} were detected.

Although, as indicated, there are some discernible trends according to rank within the humic coals, the most obvious differences are between the humic and cannel coals. The cannel coals gave extra large yields of paraffins, olefins, and other nonaromatic neutral oil constituents, reflecting the greatly different structure of these coals, which are in the sapropelic deposit series rather than the normal or humic coal series. Cannel, or "candle" coals because of their ready combustibility, are generally made up of the highly "oily" or "waxy" degradation products of microscopic plant and animal life, such as algae, spores or pollen grains, sporophylls, and plankton (7). Such organic remains when mixed with mud generally produce oil shale. The atomic C-H ratio of cannel coals is generally not greater than about 1.0, similar to oil shales, even though the weight-percent carbon can be as high as that for a high rank bituminous coal in the ASTM classification of humic coals by rank (7).

CONCLUSIONS

1. There was some evidence of dependence of yield on rank within the humic coals. For example, benzene, toluene, and m-xylene yields generally declined with decrease in rank; yields of total naphthalenes clearly decreased with decrease in rank; yields of total tar acids definitely declined with decrease in rank, although the five lowest boiling phenols totaled about 5 or 6 pounds per ton for all five normal coals; and there was an increase in yield of total olefins with decrease in rank.

2. The cannel coals, which are sapropelic rather than normal or humic coals, gave extra large yields of paraffins, olefins, and other nonaromatic neutral oil and light oil constituents, reflecting the greatly different structure of these coals. For example, the yield of total straight-chain paraffins and olefins in the carbon number range C_5 through C_{36} from both cannel coals was around 113 pounds per ton of dry coal.

3. High volatile A bituminous coals from different locations in the Pittsburgh seam gave distinctly different results. For example, the Arkwright mine coal gave higher yields of both light oil and tar than did Consolidation No. 9 mine coal.

4. Total naphthalenes, which included alkylation as high as pentamethyl for all seven coals, fell in the range of about 4 to 11 pounds per ton for all the coals. Highly alkylated quinolines made up the bulk of the distillable tar bases from all seven coals.

5. There was some evidence of a partial approach to thermodynamic equilibrium for the products from all seven coals. For example, the predominant xylene isomer was m-xylene; the most prevalent of the six xylenol isomers was 2,4-xylenol; 2,4-dimethylquinoline was present in the largest amounts; and there was more 2-methylnaphthalene than 1-methylnaphthalene.

LITERATURE CITED

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Table I. - Coals Used in the Fixed-Bed Carbonizer

Code	Rank of Coal[a]	Mine	County	State	Carbon, wt-pct[b]	Atomic C-H ratio	Ash, wt-pct
BA	Bituminous (hva)[c]	Arkwright	Monongalia	West Virginia	84.6	1.279	7.9
BC	Bituminous (hva)[c]	Consolidation No. 9	Marion	West Virginia	82.4	1.278	6.4
BS	Bituminous (hvb)	Lower Sunnyside Bed No. 1	Carbon	Utah	82.1	1.214	7.1
SBE	Subbituminous	Eagle	Weld	Colorado	76.1	1.211	6.4
LS	Lignite	Sandow	Milam	Texas	72.9	1.109	13.5
CIC	Cannel	Island Creek No. 13	Logan	West Virginia	86.3	0.989	17.7
CL	Cannel	Leatherwood No. 4	Clay	West Virginia	86.7	0.973	8.7

[a] Cannel coals cannot be included in the ranking of normal coals.

[b] Moisture- and ash-free basis.

[c] These two coals were obtained from the same Pittsburgh seam, but in different counties.

Table II. - Light Oils

Compound	Pounds per ton of dry coal						
	BA	BC	BS	SBE	LS	CIC	CL
Aliphatics							
n-Pentane, 1-Pentene	0.20	0.08	0.06	----	0.66	3.39	2.89
n-Hexane	0.61	0.23	0.30	0.06	0.56	6.63	4.82
1-Hexene	0.31	0.13	0.23	0.03	0.54	6.09	4.34
n-Heptane	0.81	0.41	0.66	0.19	0.58	6.39	6.51
1-Heptene	0.61	0.38	0.49	0.13	0.54	6.09	2.89
n-Octane	1.12	0.36	0.73	0.25	0.54	5.54	3.86
1-Octene	0.71	0.23	0.47	0.14	0.41	4.70	3.13
n-Nonane	1.32	0.19	0.53	0.32	0.46	2.08	1.21
1-Nonene	0.81	0.10	0.41	0.16	0.24	2.00	0.96
n-Decane	0.81	0.07	0.26	0.22	0.19	0.23	0.24
1-Decene	0.20	0.03	0.13	0.08	0.12	0.15	0.12
Total	7.51	2.21	4.27	1.58	4.84	43.29	30.97
Aromatics							
Benzene	1.63	1.03	0.83	0.40	1.44	2.16	2.89
Toluene	7.95	2.88	2.99	2.02	2.53	4.62	4.82
Ethylbenzene	1.22	0.31	0.43	0.42	0.32	0.62	0.48
p-Xylene	1.83	0.34	0.58	0.38	0.17	0.31	0.24
m-Xylene	4.89	1.00	1.11	0.90	0.71	0.77	0.72
o-Xylene	1.94	0.34	0.58	0.52	0.32	0.46	0.24
Isopropylbenzene	0.20	----	----	----	----	----	----
n-Propylbenzene	0.20	0.31	----	0.10	----	----	----
p-Ethyltoluene, m-Ethyltoluene	2.14	0.17	0.36	0.32	0.07	----	----
1,3,5-Trimethylbenzene	0.51	0.06	0.09	0.04	----	----	----
o-Ethyltoluene	0.20	0.03	0.04	0.08	----	----	----
Total	22.71	6.19	7.01	5.18	5.56	8.94	9.39
Total light oils	40.77	11.40	12.80	8.40	13.40	61.60	48.20

Table III. - Fractions Obtained by Solvent Extraction

	Pounds per ton of dry coal						
	BA	BC	BS	SBE	LS	CIC	CL
Resins (cyclohexane insolubles)	54.45	52.48	73.18	19.50	28.75	15.55	35.12
Tar acids	58.35	50,12	44.74	32.56	20.31	18.13	54.13
Tar bases[a]	9.81	6.21	6.61	2.41	4.15	10.27	10.67
High-quality neutral oils	84.70	63.17	70.87	42.47	92.57	292.98	333.29
Other neutral oils	73.54	60.94	45.02	19.49	31.11	204.10	161.38
Resinoids	27.98	13.33	9.53	7.70	26.70	50.11	39.66
Total tar	314.40	246.25	249.95	124.13	204.09	586.80	624.25

[a] All impure; table IV lists tar bases.

Table IV. - Tar Bases (Quinolines)

Compound	Total tar bases, weight percent						
	BA	BC	BS	SBE	LS	CIC	CL
Quinoline	0.03	0.02	0.06	0.16	0.07	0.01	0.51
2-Methylquinoline	0.08	0.07	0.12	0.63	0.40	0.03	0.94
8-Methylquinoline	0.05	0.20	0.24	0.47	0.18	0.02	0.68
7-Methylquinoline 6-Methylquinoline	0.18	0.54	0.48	1.02	0.47	0.09	1.54
4-Methylquinoline	0.18	0.42	0.24	0.94	0.91	0.07	0.94
2,6-Dimethylquinoline	0.23	1.13	0.48	1.81	2.03	0.13	1.79
2,4-Dimethylquinoline	0.52	1.81	1.08	2.67	2.25	0.18	4.36
Total tar bases, wt-pct of dry tar	2.28	0.43	0.66	0.38	0.22	0.60	0.98
Total tar bases, lbs/ton of dry coal	7.17	1.06	1.65	0.47	0.45	3.50	6.19

Table V. - Low-Boiling Tar Acids

Compound	Pounds per ton of dry coal						
	BA	BC	BS	SBE	LS	CIC	CL
Phenol	0.83	1.03	0.76	1.07	1.73	----	0.41
o-Cresol	1.90	1.84	1.19	1.01	1.25	0.42	1.01
2,6-Xylenol	0.58	0.61	0.39	0.11	0.17	0.42	0.47
p-Cresol	1.00	1.03	0.96	1.09	1.39	0.27	0.68
m-Cresol	1.65	2.04	1.43	1.65	1.49	0.31	0.58
Total	5.96	6.55	4.73	4.93	6.03	1.42	3.15
o-Ethylphenol	0.48	0.54	0.15	0.16	0.24	0.46	0.33
2,4-Xylenol	1.24	1.53	0.84	0.45	0.55	0.84	1.42
2,5-Xylenol	0.97	1.12	0.67	0.42	0.45	0.69	0.64
2,4,6-Trimethylphenol	0.27	0.35	0.15	0.03	0.07	0.52	0.41
2,3-Xylenol	0.12	0.20	0.13	0.09	0.21	0.21	0.19
p-Ethylphenol	0.19	0.11	0.06	0.09	0.31	0.25	0.19
2,3,6-Trimethylphenol	0.10	0.23	0.10	0.07	0.17	0.15	0.23
m-Ethylphenol	0.22	0.24	0.08	0.09	0.28	0.15	0.21
3,5-Xylenol	0.15	0.29	0.11	0.10	0.24	0.15	0.16
2-n-Propylphenol	0.12	0.17	0.03	0.01	0.03	0.13	0.08
3,4-Xylenol	0.12	0.06	0.03	0.01	0.10	0.15	0.08
Total	3.98	4.84	2.35	1.52	2.65	3.70	3.94
Total tar acids	58.35	50.12	44.74	32.56	20.31	18.13	54.13

Table VI. - High-Quality Neutral Oils

Compound	Pounds per ton of dry coal						
	BA	BC	BS	SBE	LS	CIC	CL
n-Paraffins	9.83	3.92	11.58	7.41	8.25	46.82	42.80
Other paraffins	7.10	8.30	9.97	3.47	9.43	14.11	43.29
Total paraffins	16.93	12.22	21.55	10.88	17.68	60.93	86.09
α-Olefins	3.17	2.65	8.00	4.81	10.88	23.47	37.92
Other olefins	3.20	3.66	7.04	3.77	13.18	69.36	48.38
Total olefins	6.37	6.31	15.04	8.58	24.06	92.83	86.30
Naphthalenes (C_{10} through C_{12})	7.28	8.09	4.29	2.19	2.70	5.05	7.06
Total naphthalenes	11.32	10.95	9.19	3.93	5.19	10.55	11.40
Biphenyls (C_{12} and C_{13})	0.34	0.64	0.41	0.46	0.48	0.47	1.20
Total high-quality neutral oils	84.70	63.17	70.87	42.47	92.57	292.98	333.29

Table VII. - Low-Boiling Naphthalenes and Biphenyls

Compound	BA	BC	BS	SBE	LS	CIC	CL
	High-Quality Neutral Oils, weight-percent						
Naphthalene	1.00	1.07	0.05	0.46	0.44	0.09	0.04
2-Methylnaphthalene	1.98	4.88	0.13	1.06	0.66	0.27	0.49
1-Methylnaphthalene	1.44	2.94	0.14	0.88	0.36	0.21	0.32
Biphenyl	0.08	0.20	0.12	0.51	0.16	0.05	0.17
1, 3-Dimethylnaphthalene, 2-Ethylnaphthalene, 1-Ethylnaphthalene	0.55	0.44	0.54	0.41	0.16	0.24	0.28
2, 6-Dimethylnaphthalene, 2, 7-Dimethylnaphthalene	1.14	1.30	0.88	0.61	0.42	0.29	0.32
1, 6-Dimethylnaphthalene, 1, 7-Dimethylnaphthalene	1.78	1.64	2.47	1.42	0.73	0.43	0.45
1, 4-Dimethylnaphthalene, 1, 5-Dimethylnaphthalene, 1, 2-Dimethylnaphthalene, 2, 3-Dimethylnaphthalene	0.71	0.52	1.85	0.30	0.14	0.18	0.22
4-Methylbiphenyl, 3-Methylbiphenyl	0.32	0.81	0.45	0.56	0.36	0.11	0.19
	Pounds per ton of dry coal						
Naphthalenes (C_{10} through C_{12})	7.28	8.09	4.29	2.19	2.70	5.05	7.06
Biphenyls (C_{12} and C_{13})	0.34	0.64	0.41	0.34	0.48	0.47	1.20

Table VIII. - Straight-chain Hydrocarbons

	Total straight-chain material, wt-pct						
Compound	BA	BC	BS	SBE	LS	CIC	CL
n-Undecane	0.71	----	0.42	0.68	----	1.28	0.19
1-Undecene	----	----	0.39	0.54	0.07	0.80	0.16
n-Dodecane	1.88	0.46	1.04	1.55	0.27	2.59	0.60
1-Dodecene	----	0.39	0.86	1.06	0.97	1.57	0.58
n-Tridecane	3.39	1.70	1.64	2.21	0.85	3.74	1.23
1-Tridecene	1.34	1.32	1.30	1.44	1.64	2.27	1.07
n-Tetradecane	4.64	2.34	2.10	2.56	1.75	4.54	2.26
1-Tetradecene	2.05	2.01	1.61	1.72	2.54	2.81	1.95
n-Pentadecane	5.45	3.33	2.49	2.80	2.56	5.11	2.88
1-Pentadecene	2.59	2.64	1.92	1.93	3.37	3.29	2.51
n-Hexadecane	5.89	4.03	2.91	2.96	3.19	5.43	3.42
1-Hexadecene	2.95	3.10	2.34	2.12	3.69	3.48	3.12
n-Heptadecane	6.16	4.65	3.22	3.27	3.33	5.46	3.74
1-Heptadecene	3.21	3.64	2.36	2.33	4.00	3.45	3.30
n-Octadecane	6.25	5.35	3.25	3.44	3.42	5.27	3.88
1-Octadecene	3.30	3.95	2.47	2.49	4.13	3.23	3.79
n-Nonadecane	5.89	5.50	3.35	3.65	3.44	4.95	4.12
1-Nonadecene	3.21	4.03	2.55	2.68	4.29	3.07	3.91
n-Eicosane	5.63	5.43	3.51	3.81	3.44	4.54	4.33
1-Eicosene	3.04	3.88	2.65	2.92	4.45	2.78	4.09
n-Heneicosane	5.18	5.35	3.64	4.02	3.44	4.09	4.47

(Continued)

(Page 2 of Table VIII)

1-Heneicosene	2.77	3.49	2.78	3.04	4.63	2.46	4.23
n-Docosane	4.46	4.50	3.84	4.21	3.42	3.64	4.49
1-Docosene	----	3.02	2.99	3.18	4.72	2.20	4.26
n-Tricosane	4.11	4.11	3.97	4.31	3.39	3.23	4.28
1-Tricosene	----	2.71	3.01	3.22	4.58	1.98	4.00
n-Tetracosane	3.57	3.57	4.05	4.28	3.19	2.78	3.93
1-Tetracosene	----	2.56	3.06	3.13	4.08	----	3.70
n-Pentacosane	3.13	2.79	4.00	4.16	2.70	2.33	3.30
1-Pentacosene	----	2.02	2.99	2.94	3.30	----	3.05
n-Hexacosane	2.68	1.94	3.77	3.65	2.16	1.92	2.44
1-Hexacosene	----	1.55	2.80	2.56	2.43	----	1.98
n-Heptacosane	2.23	1.39	3.45	3.18	1.69	1.56	1.53
1-Heptacosene	----	----	2.57	2.05	1.91	----	1.28
n-Octacosane	1.79	1.16	2.93	2.26	0.90	1.25	0.98
1-Octacosene	----	----	2.23	----	0.85	----	----
n-Triacontane	1.34	0.93	2.42	1.81	0.65	1.02	0.56
n-Dotriacontane	0.80	0.70	1.64	1.01	0.45	0.83	0.39
n-Tetratriacontane	0.36	0.46	1.01	0.59	0.25	0.64	----
n-Hexatriacontane	----	----	0.47	0.24	0.04	0.41	----
	Pounds per ton of dry coal						
Paraffins	9.83	3.92	11.58	7.41	8.25	46.82	42.80
Olefins	3.17	2.65	8.00	4.81	10.88	23.47	37.92
Total straight chains	13.00	6.57	19.58	12.22	19.13	70.29	80.72

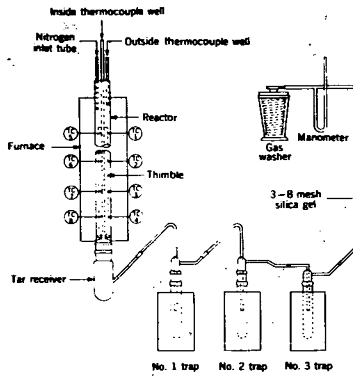

Figure 1. - Schematic Diagram of Carbonizer and Collecting System.

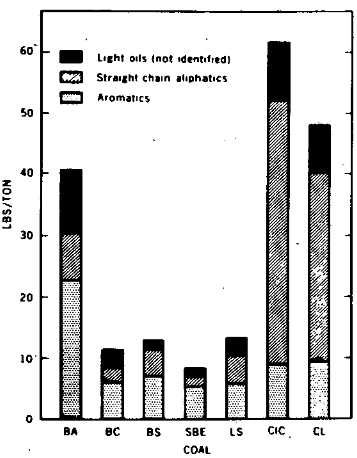

Figure 2. - Light Oils.

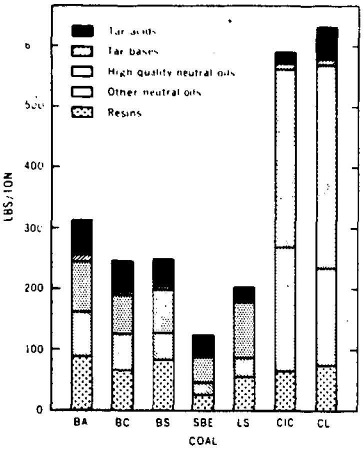

Figure 3. - Fractions Obtained by Solvent Extraction.

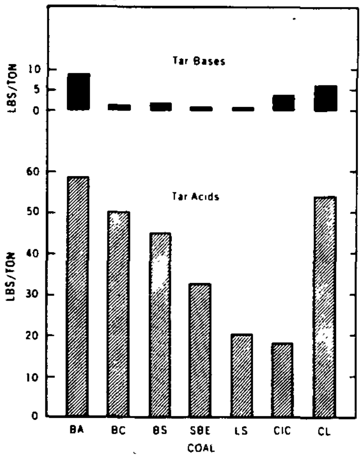

Figure 4. - Total Tar Acids and Pure Tar Bases.

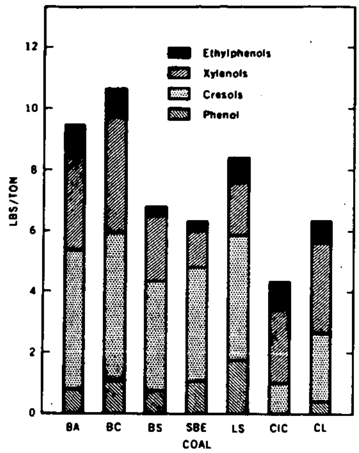

Figure 5. - Low-Boiling Tar Acids.

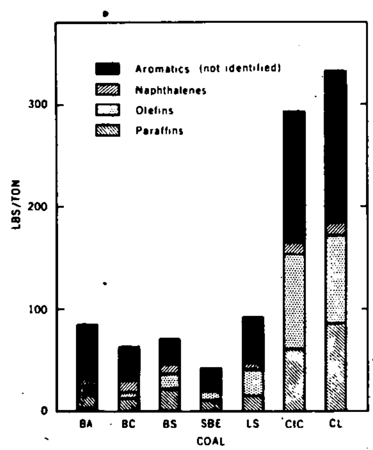

Figure 6. - High-Quality Neutral Oils.

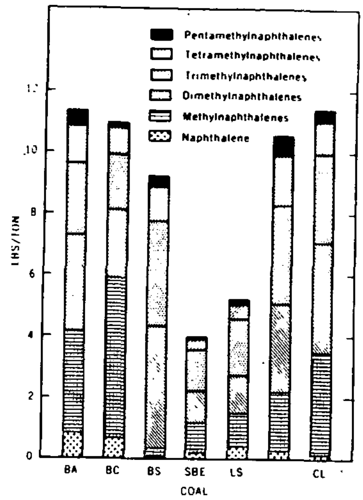

Figure 7. - Totals of All Naphthalene Classes.

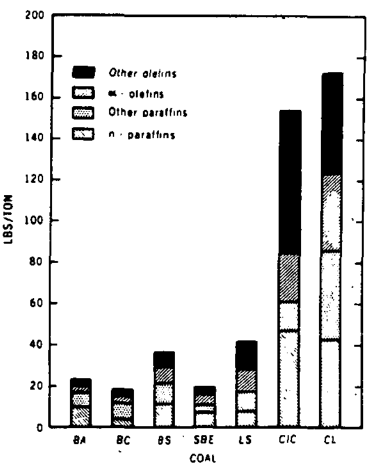

Figure 8. - Classes of Aliphatics.